Compton polarimeter update for EIC

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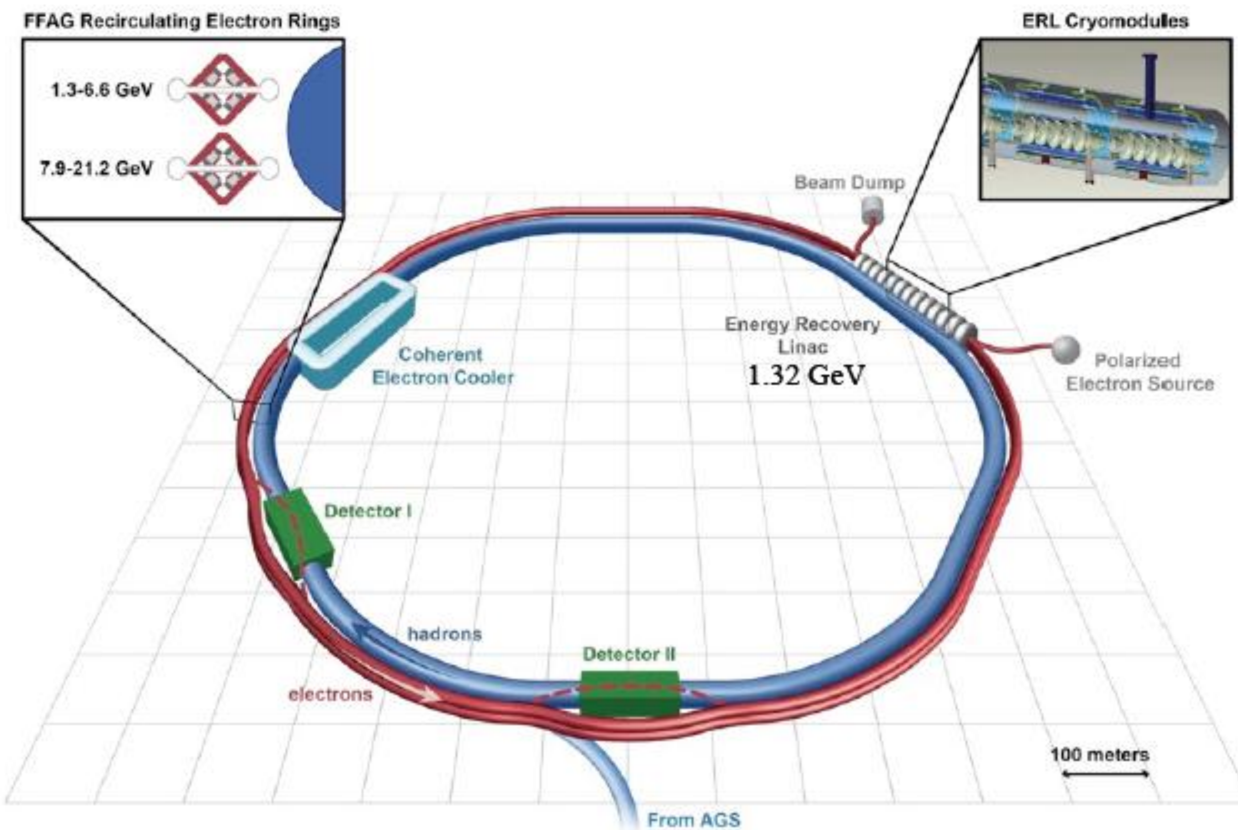
EIC R&D meeting
January 23rd 2015

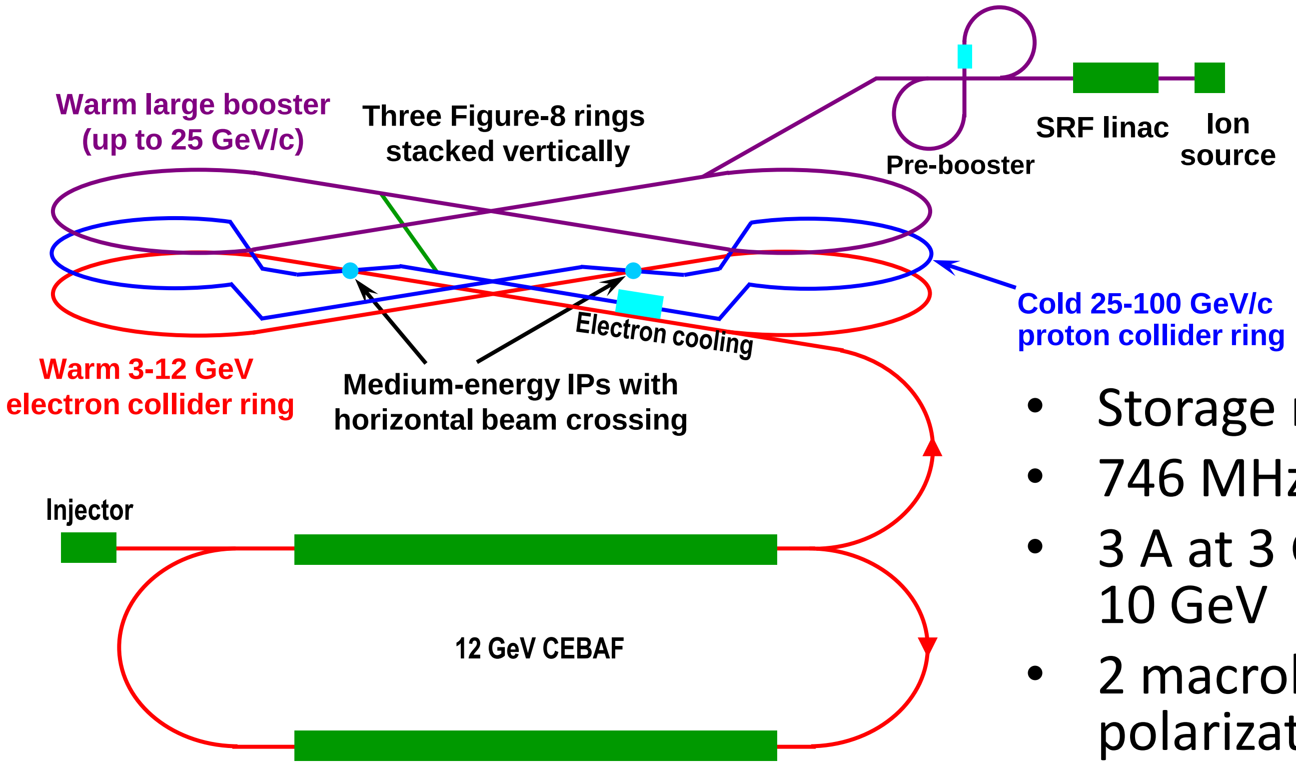
ERHIC



- 6.6 GeV to 21.2 GeV
- ~10 MHz Repetition rate
- Up to 21 recirculations
- 50 mA with "gatling gun" design
- 80 % min polarization
- Similar to CEBAF

Vadim Ptitsyn
eRHIC Accelerator Design
EIC2014

MEIC

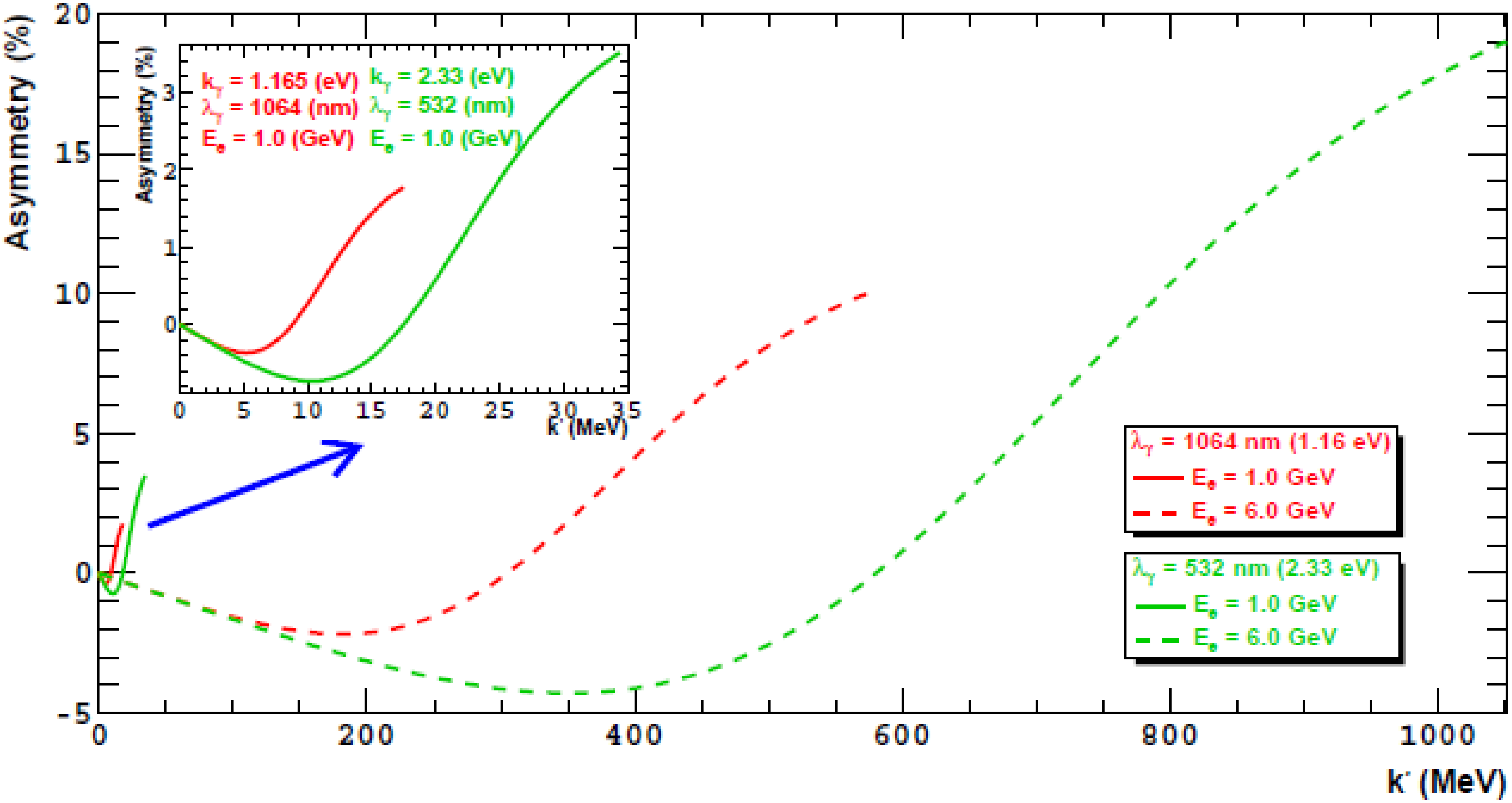


- Storage ring – Ring ring
- 746 MHz
- 3 A at 3 GeV and 180 mA at 10 GeV
- 2 macrobunch with one polarization 2.3 us
- Measure polarization average of the two macrobunch
- Every electron bunch crosses every ion bunch

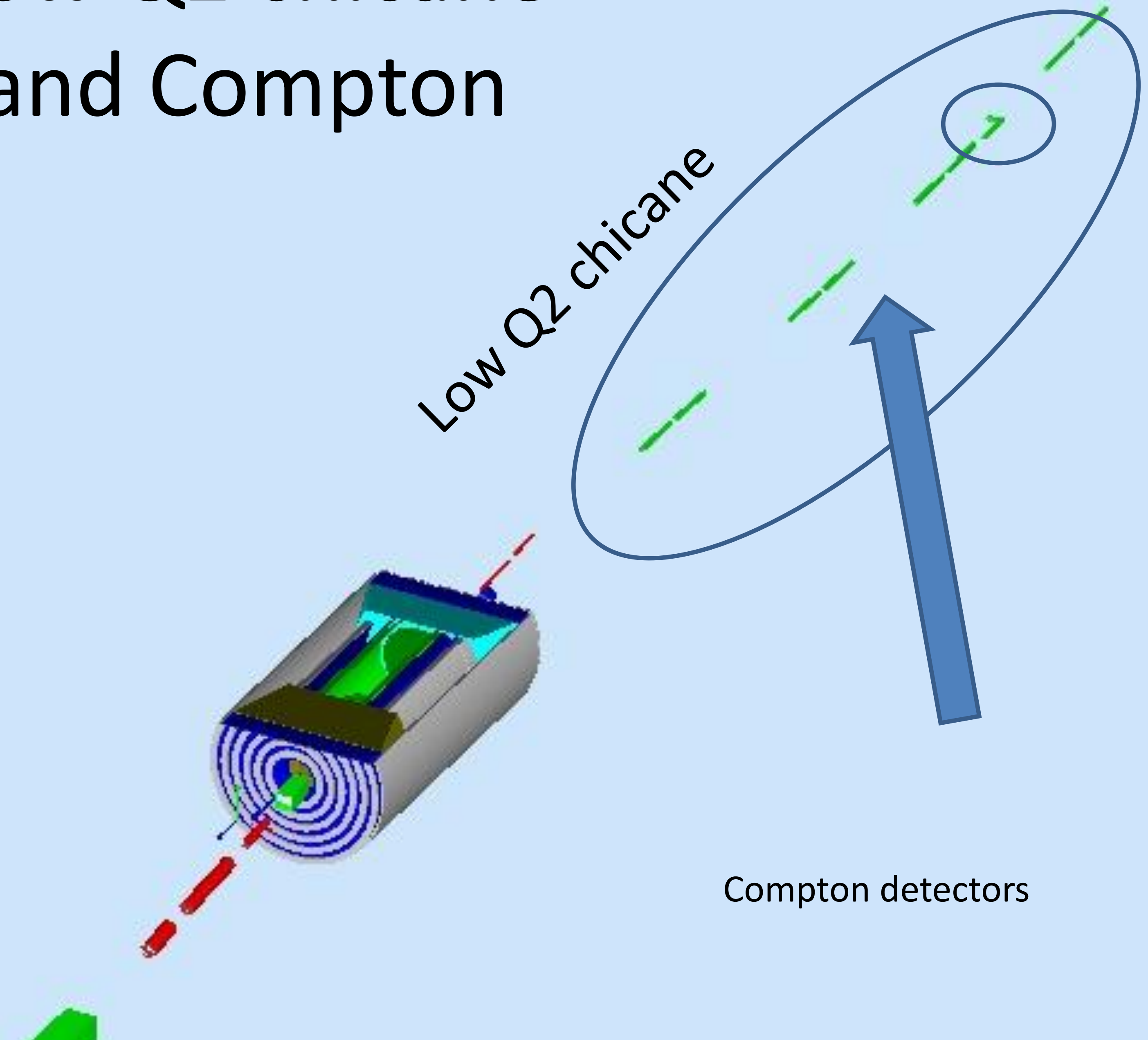
Compton asymmetry

$\sigma(\ e + \gamma \longrightarrow e' + \gamma'\ ) \neq \sigma(\ e + \gamma \longrightarrow e' + \gamma'\ )$

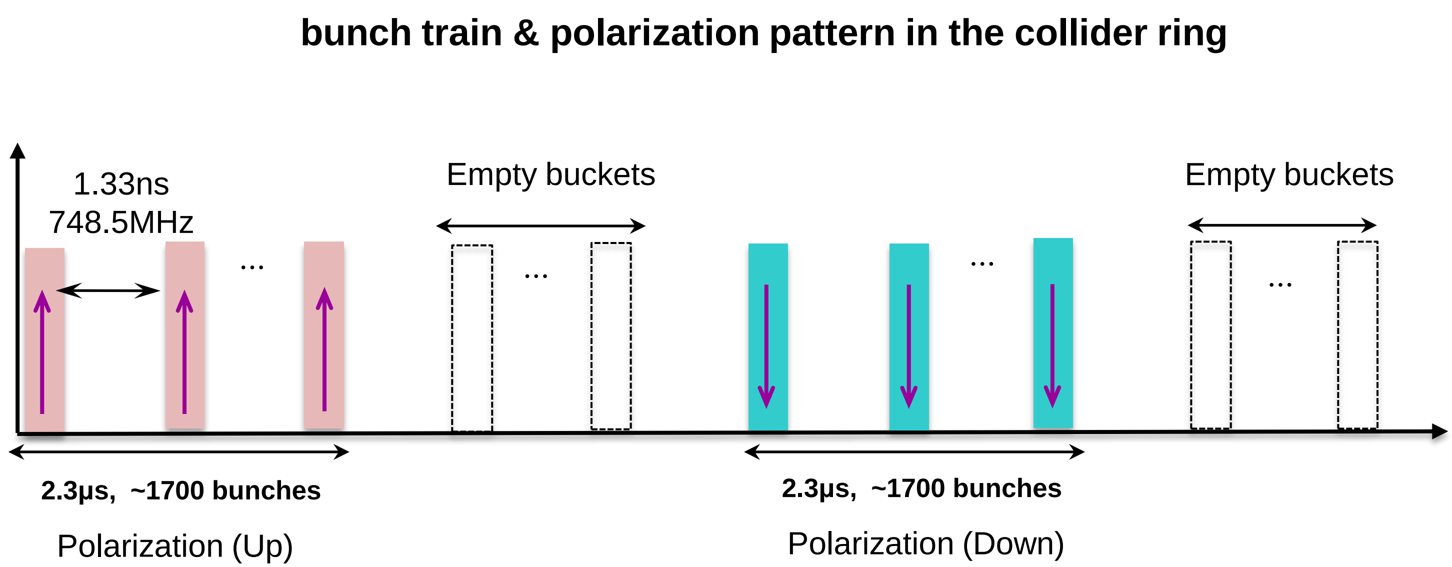
$$\frac{N^{+}-N^{-}}{N^{+}+N^{-}}\left(E_e, k_\gamma, k_{\gamma'}\right) = P_e * A(E_e, k_\gamma, k_{\gamma'})$$



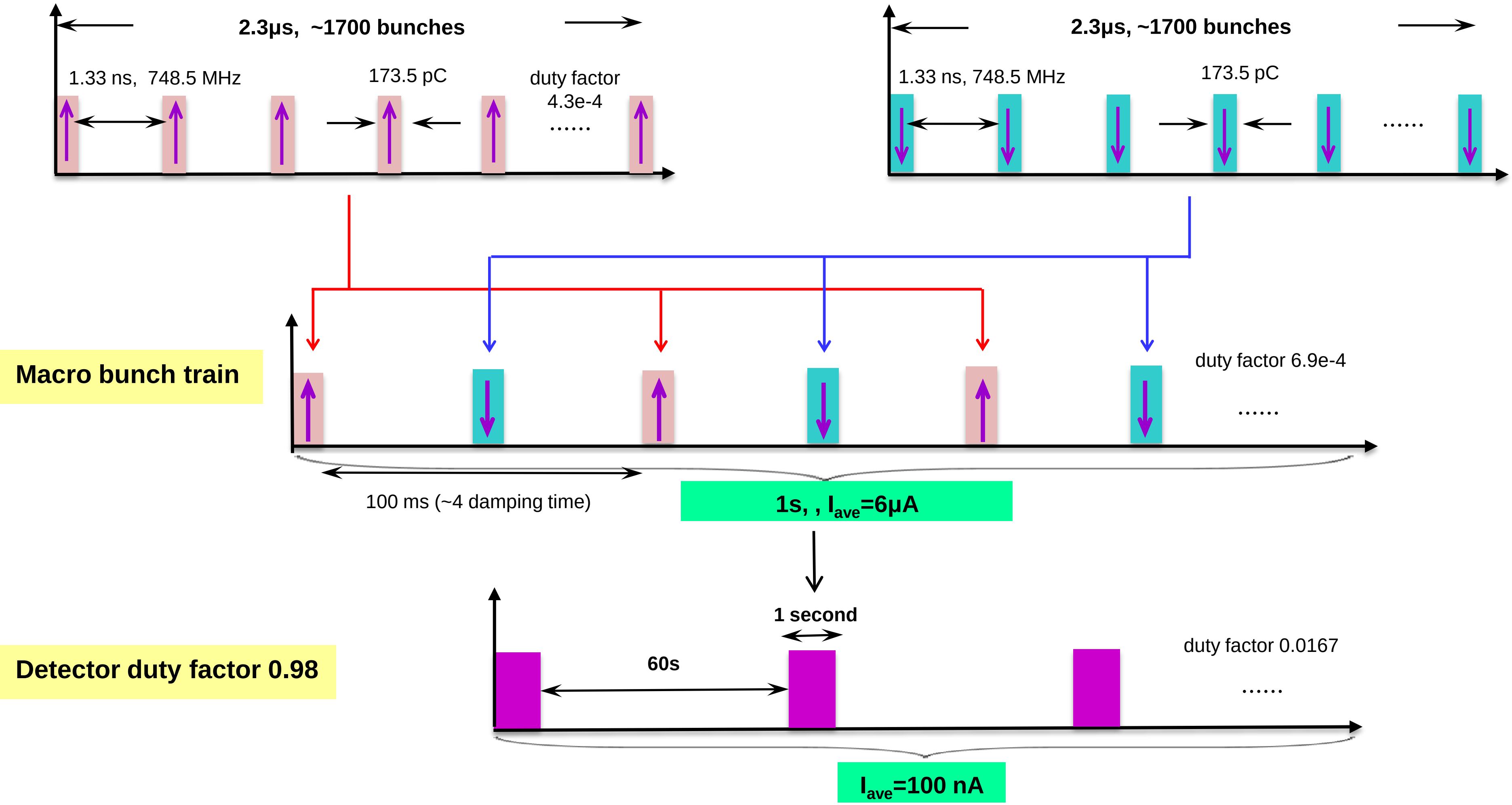
Low Q2 chicane and Compton



MEIC Bunch Structure In Collider Ring



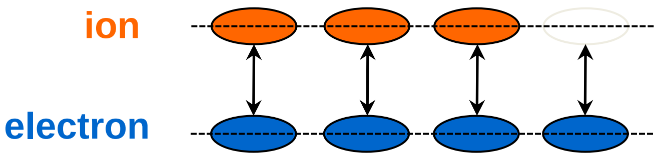
MEIC Bunch Pattern for Continuous Injection



- At 100nA average injected current, **P_{equ}/P_0> 96%** for the whole energy range

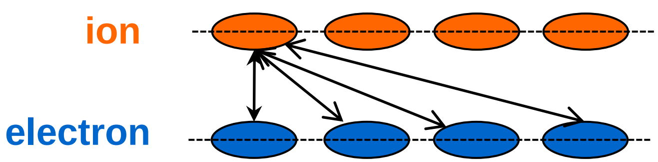
Polarization Collision Pattern

- HERA:
  - Each ion bunch only sees the same electron bunch



$$FOM \propto \left\langle \sum_j q_{ion,j} q_{ele,j} P_{ion,j}^2 P_{ele,j}^2 \right\rangle$$

- MEIC:
  - Each ion bunch sees all electron bunches



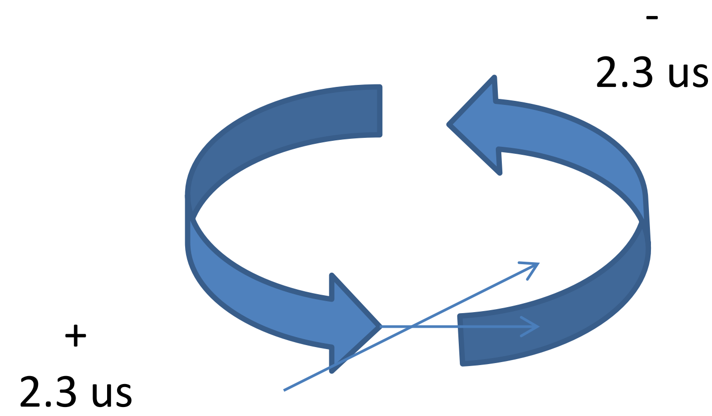
$$FOM \propto \left\langle \sum_m q_{ion,m} P_{ion,m}^2 \right\rangle \left\langle \sum_n q_{ele,n} P_{ele,n}^2 \right\rangle$$

  - No non-colliding bunches

➡ Therefore, in the MEIC
  - Bunch-to-bunch variation does not contribute to the uncertainty
  - One can measure average polarization of each macro bunch train

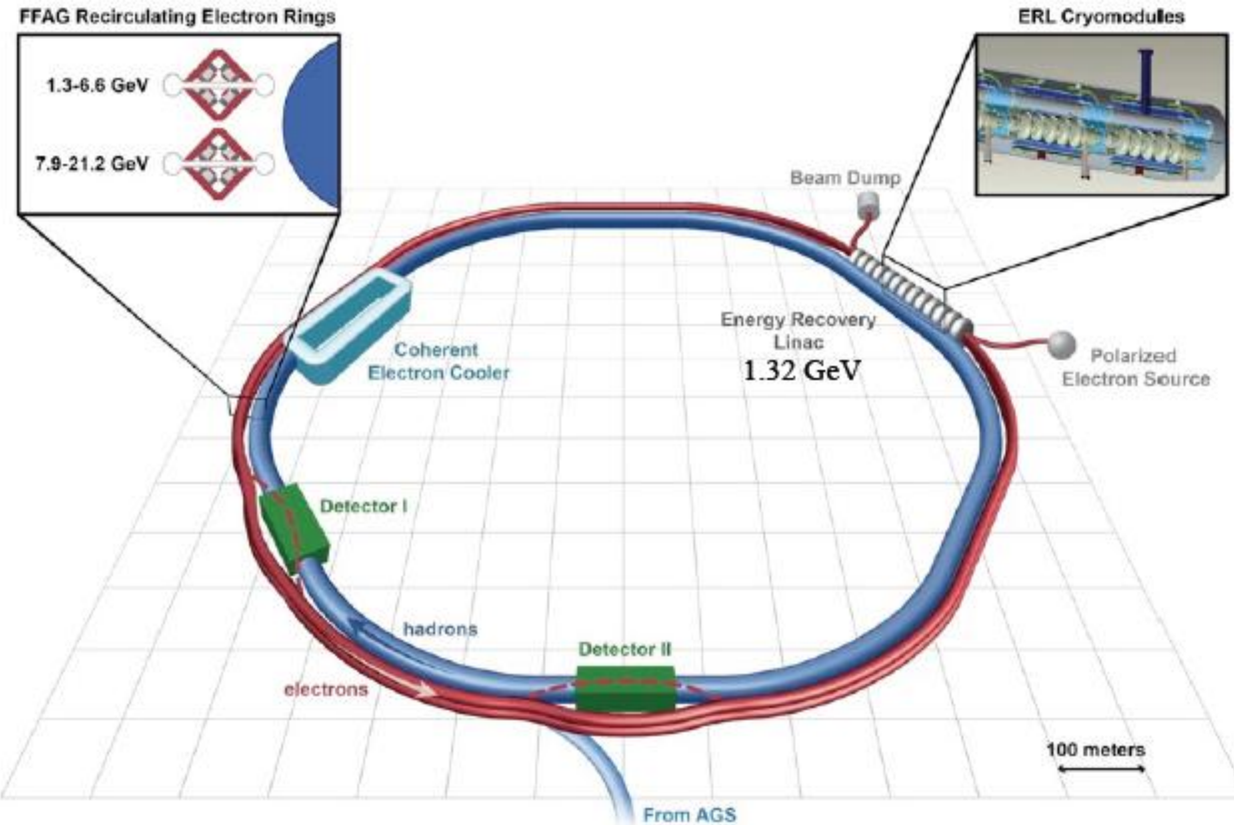
Time structure

- Bunch to bunch : 1.33 ns
- Polarization state : 2.3 us



- Measure asymmetry for one laser state and polarization

ERHIC



- 5 GeV to 21.2 GeV
- 10.8 MHz Repetition rate
- 50 mA with "Gatling gun" design with 20 sources
- Need to measure each sources polarization
- 80 % min polarization
- Similar to CEBAF

eRHIC beam parameters

- 50 mA with up to 20 sources
- 10.8 MHz repetition rate
- ERL LINAC allows helicity structure with helicity flip from the source
- Need individual measurement of each source
  - 100 ns max for each measurement
  - Logic signal to flag which source is recorded
- Rates sufficient to measure all sources in a few minutes

Compton rates

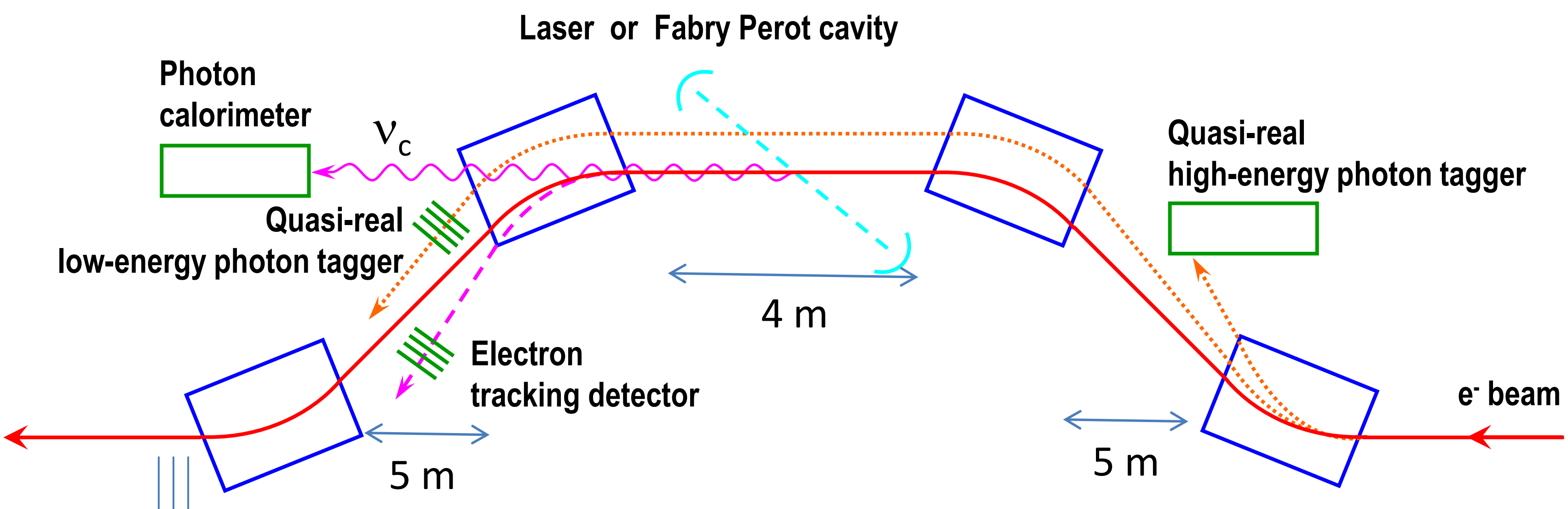
- Green laser, 1.3 degrees crossing angle
- beam 350 um

Energy	Rate (kHz/W/A)	Max current (A)	Rate kHz/W	eRHIC current (A)	Rate (kHZ/W)
3	316	3	948	0.05	15.8
5	298	3	894	0.05	14.9
6	290	2	580	0.05	14.5
7	283	1.1	311.3	0.05	14.1
9	269	0.4	107.6	0.05	13.4
11	258	0.18	46.44	0.05	12.9

- laser of a few watts : 10 KHz to 1 MHz - sufficient statistics in a few seconds
- 1000 W cavity : rates from tens of KHz to MHz level (if background high)

Electron detector implementation in low Q^2

- Compton polarimeter in low-Q^2 chicane
- Same polarization as at the IP due to zero net bend
- Non-invasive continuous polarization monitoring
- Polarization measurement accuracy of ~1% expected
- No interference with quasi real photon tagging detectors

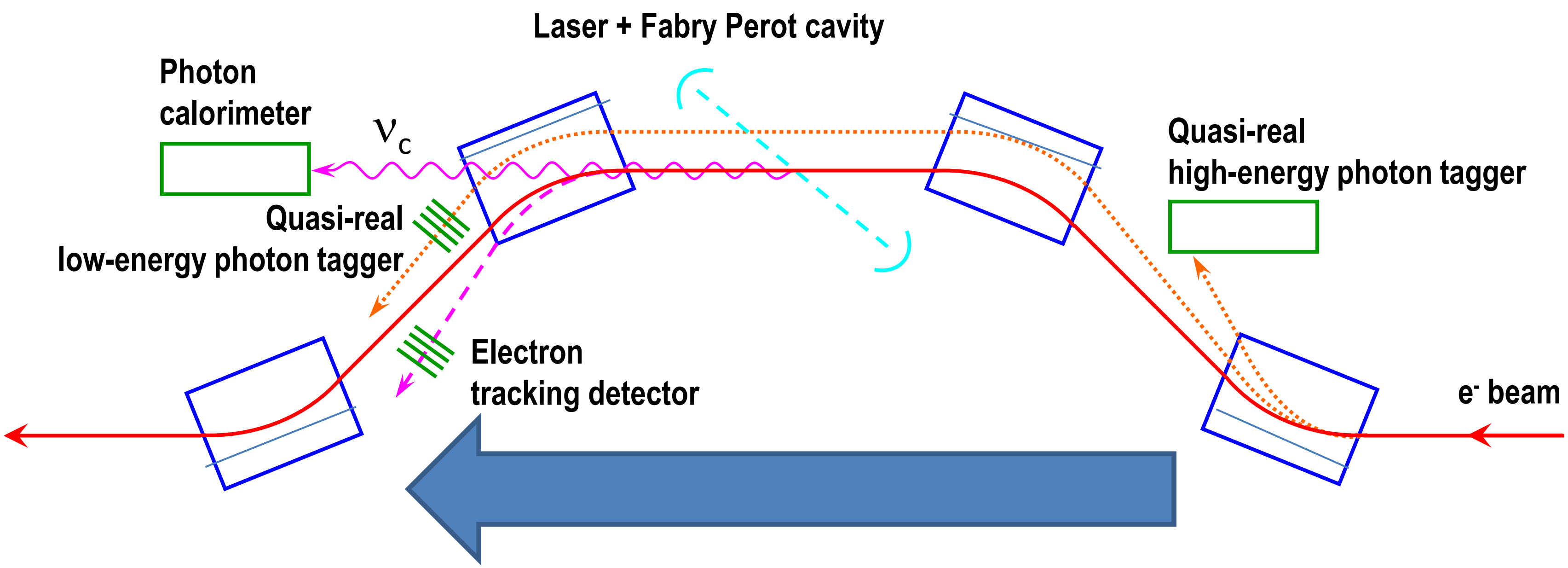


D = -22.4 cm
D' = -0.04
At 10 GeV assume L = 5 m
Compton edge : 2.6 GeV = 5.8 cm +0.0104*L = 10.84 cm
Zero crossing 1.514 GeV = 3.39 cm + 0.006*L = 6.39 cm

Detector in vacuum

Chicane

- Different type of magnet for
- dipole 1 and 4 can be C magnets
- Dipole 2 and 3 can be C magnets in other direction or open dipoles



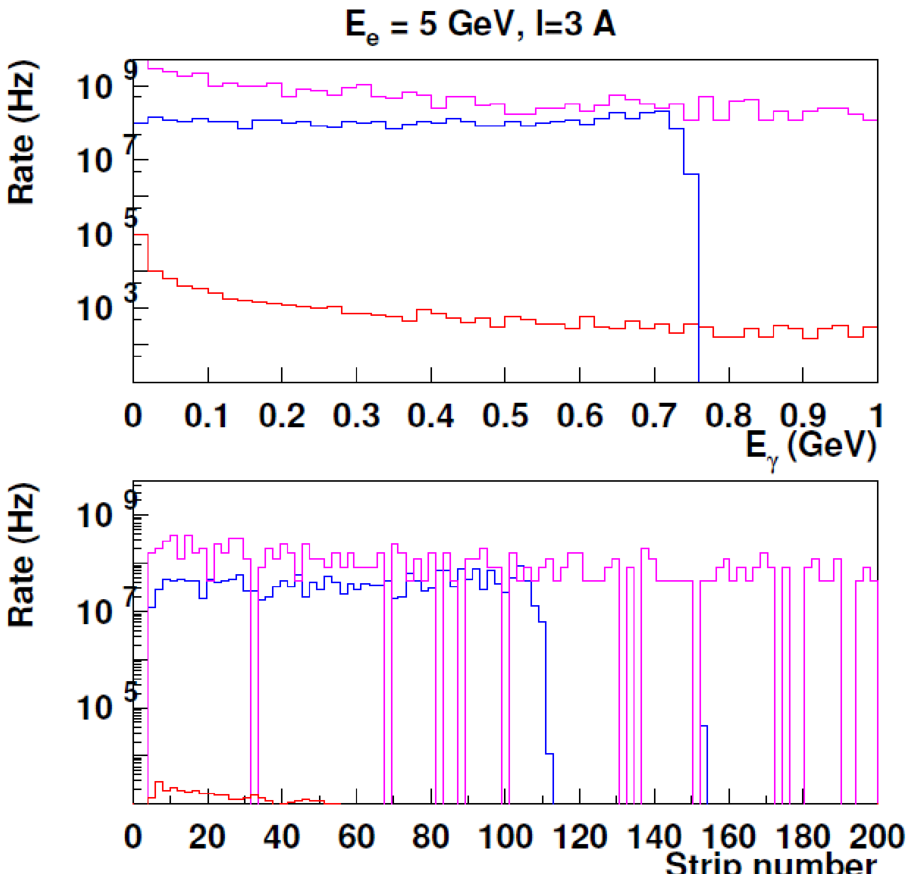
Beam size shrinks with distance to interaction point : reduction of halo in detector

Simulation

- Simulation Dave Gaskell (small aperture) 15 meter setup

Photon

Electron



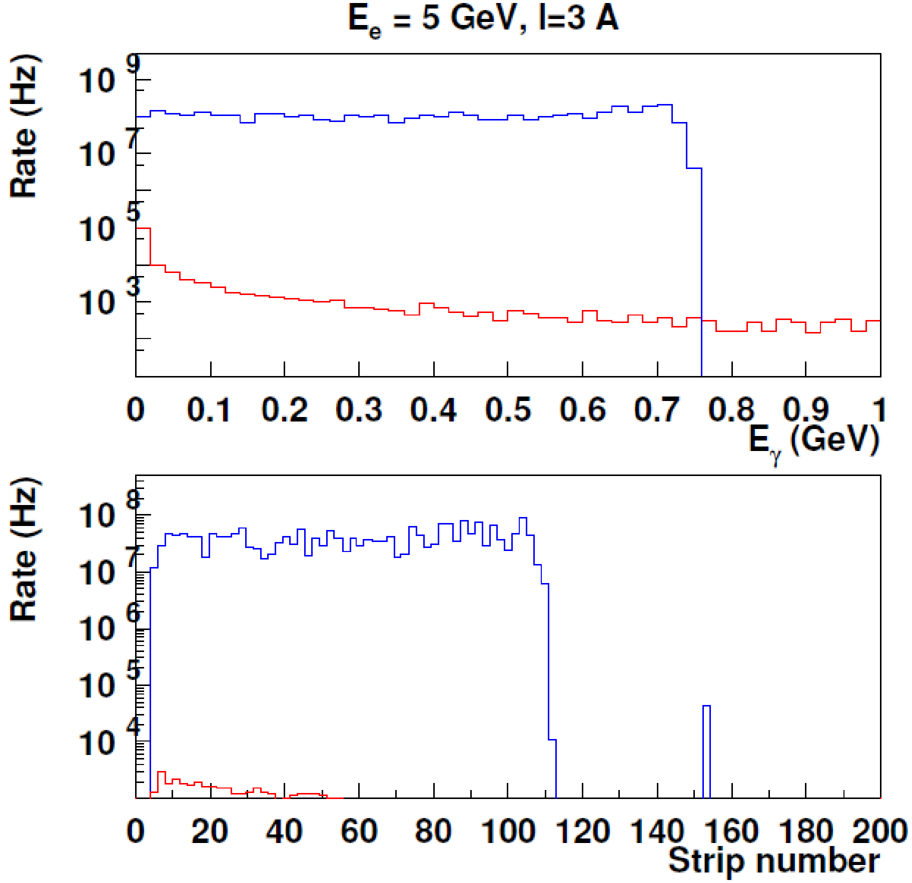
- Very sensitive to Halo
- Simulation for cavity design

Simulation

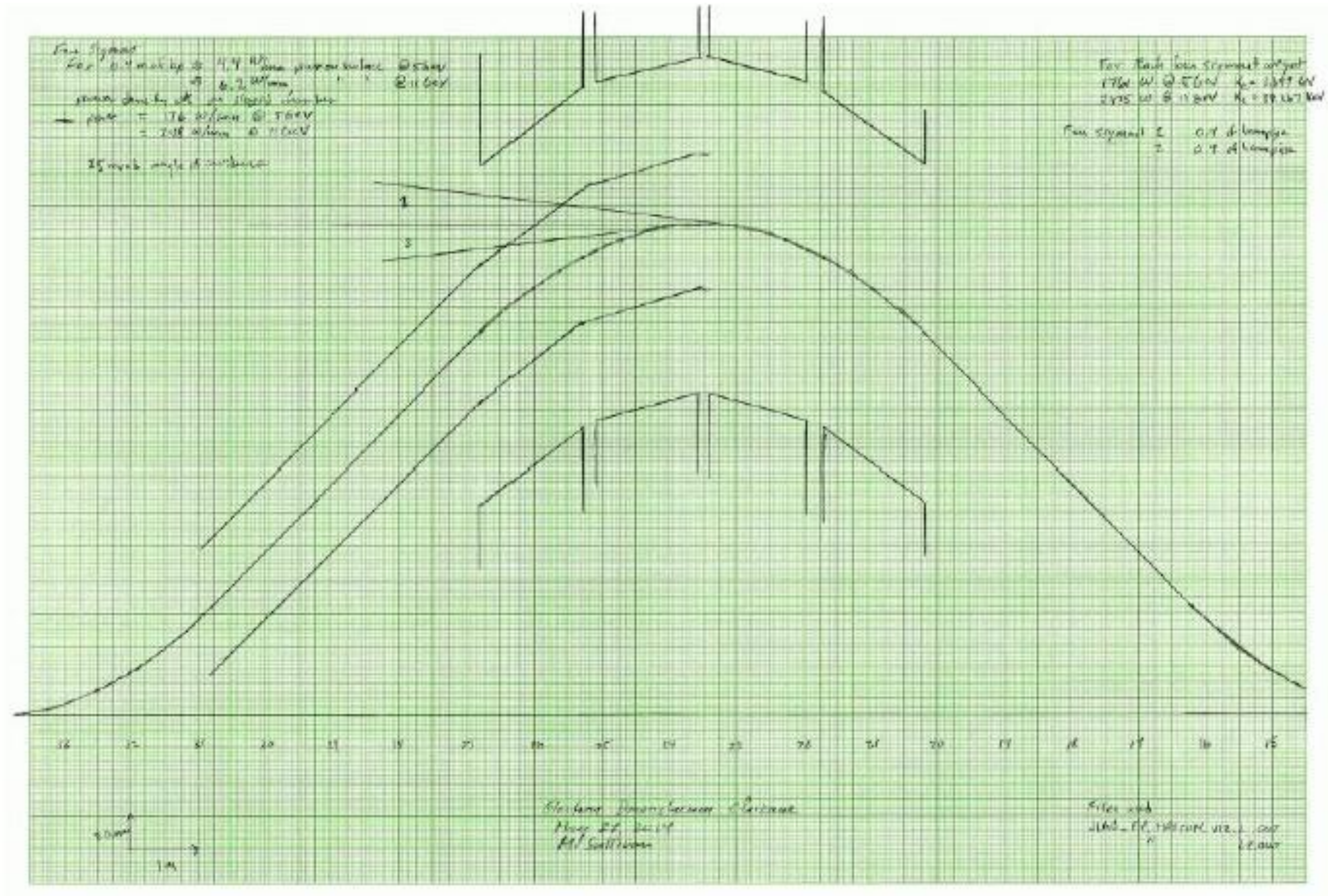
- Simulation Dave Gaskell (large aperture) 15 meters setup

Photon

Electron



Photon detector
Synchrotron radiation study
(Mike Sullivan)



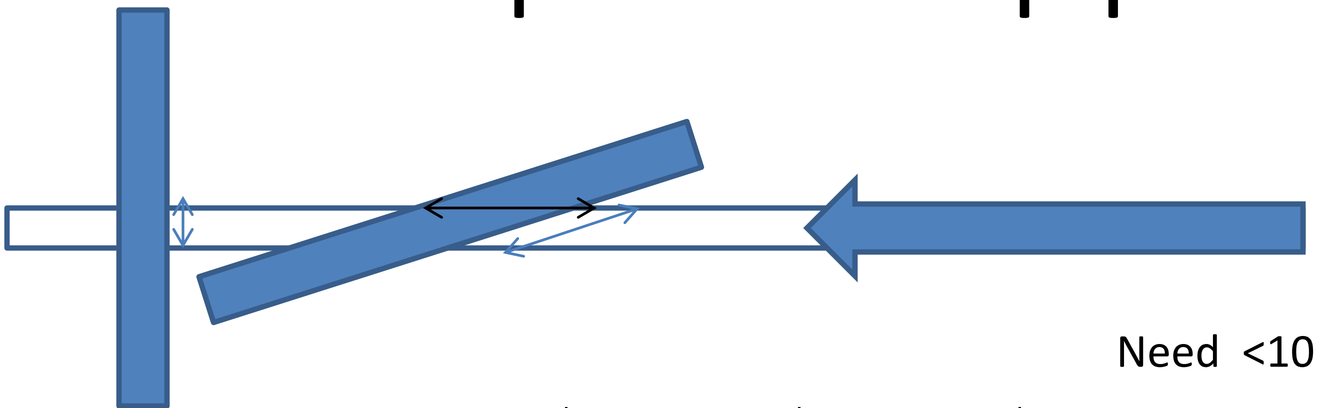
Beam pipe

Table 2. Summary of penetration factors for various beam pipe designs and for the 5 GeV and 11 GeV electron beam energies.

Beam pipe options	1 mm Be, 2 mm H_2O, 1 mm Be		10 μm Au, 1 mm Be, 2 mm H_2O, 1 mm Be		25 μm Au, 1 mm Be, 2 mm H_2O, 1 mm Be	
5 GeV e- beam 25 mrad inc. angle 4.830×10^{13} γs/bun. inc. 5.498×10^{13} keV/bun. inc.		Fraction with solid ang. cut applied (3.46×10^{-4})		Fraction with solid ang. cut applied (3.46×10^{-4})		
Frac. of inc. γs through bp	0.003715	1.285×10^{-6}	1.184×10^{-5}	4.097×10^{-9}		
Frac. of inc. enr. through bp	0.01626	5.626×10^{-6}	5.764×10^{-5}	1.994×10^{-8}		
11 GeV e- beam 25 mrad inc. angle 6.371×10^{12} γs/bun. inc. 7.729×10^{13} keV/bun. inc.				Fraction with solid ang. cut applied (2.103×10^{-2})		Fraction with solid ang. cut applied (2.254×10^{-3})
Frac. of inc. γs through bp			0.0103	2.166×10^{-4}	4.467×10^{-3}	1.007×10^{-5}
Frac. of inc. enr. through bp			0.0267	5.615×10^{-4}	0.0116	2.615×10^{-5}

X-ray reduction

Sloped beam pipe



Need <10 W / mm

Beam parameters			E (GeV)	5.0			
			I (A)	3.0			
Magnet segment	SR pwr (W)	Bend angle (mrad)	Crit. energy (k_c) keV	Beam pipe W/mm perp.	Beam pipe W/mm sloped	Surface of perp. pipe hit (mm)	Surface of sloped pipe hit (mm)
Before (#1)	1761	5.007	3.7	176	4.4	10	400
After (#2)	1761	5.007	3.7	176	4.4	10	400
Det. SA	4396	12.5	3.7				
Beam parameters			E (GeV)	11.0			
			I (A)	0.18			
Before (#1)	2475	5.007	39.4	248	6.2	10	400
After (#2)	2475	5.007	39.4	248	6.2	10	400
Det. SA	6179	12.5	39.4				

Energy deposit in photon detector for different shielding

11 GeV beam with soft bend magnets (critical energy = 18.45 keV)				
	Frac. of inc. γs thru sheet	γs thru to the detector/bunch	Fraction of inc. energy thru sheet	Energy/bunch on the detector (GeV)
1.71×10^{8} γ/bunch 4.06×10^{9} keV/bun.	Beam pipe: 10 µm Au, 1 mm Be, 2 mm H_2O and 1 mm Be			
2 mm Cu sheet	0.245	4.19×10^{7}	0.287	1.16×10^{3}
1 mm Cu sheet	0.470	5.50×10^{7}	0.509	2.06×10^{3}
6.36×10^{6} γ/bunch 1.60×10^{8} keV/bun.	Beam pipe: 25 µm Au, 1 mm Be, 2 mm H_2O and 1 mm Be			
2 mm Cu sheet	0.291	1.85×10^{6}	0.327	52.2
1 mm Cu sheet	0.527	3.35×10^{6}	0.556	88.9
2 mm Ag sheet	3.00×10^{-2}	1.91×10^{5}	4.92×10^{-2}	7.87
2 mm Pb sheet	4.22×10^{-3}	2.68×10^{4}	4.48×10^{-3}	0.716
3 mm Pb sheet	3.25×10^{-4}	2.07×10^{3}	3.49×10^{-4}	0.0558

Need to evaluate effect on detector performances

Radiation dose

E Loss(MeV/cm-1)			L	Thickness	Width	Volume (cm^3)	Density	Mass (g)			
3.87			5	0.025	0.035	0.004375	2.329	0.010189375			3 MRad
	Energy	Rate (kHz/A/W)	Current	Rate kHz	1/Rate (s)	E deposit (MeV/W)	E deposit (J/W)	Dose (rad/W)	Dose /hour	Dose / day	N days
MEIC	3	316	3	948	1.05E-06	3.67E+06	5.87E-07	5.76E+00	2.07E+04	4.98E+05	6.03E+00
	5	298	3	894	1.12E-06	3.46E+06	5.54E-07	5.43E+00	1.96E+04	4.69E+05	6.39E+00
	6	290	2	580	1.72E-06	2.24E+06	3.59E-07	3.52E+00	1.27E+04	3.05E+05	9.85E+00
	7	283	1.1	311.3	3.21E-06	1.20E+06	1.93E-07	1.89E+00	6.81E+03	1.63E+05	1.84E+01
	9	269	0.4	107.6	9.29E-06	4.16E+05	6.66E-08	6.54E-01	2.35E+03	5.65E+04	5.31E+01
	10	258	0.18	46.44	2.15E-05	1.80E+05	2.88E-08	2.82E-01	1.02E+03	2.44E+04	1.23E+02
eRHIC	3	316	0.05	15.8	6.33E-05	6.11E+04	9.78E-09	9.60E-02	3.46E+02	8.30E+03	3.62E+02
	5	298	0.05	14.9	6.71E-05	5.77E+04	9.23E-09	9.05E-02	3.26E+02	7.82E+03	3.83E+02
	6	290	0.05	14.5	6.90E-05	5.61E+04	8.98E-09	8.81E-02	3.17E+02	7.61E+03	3.94E+02
	7	283	0.05	14.15	7.07E-05	5.48E+04	8.76E-09	8.60E-02	3.10E+02	7.43E+03	4.04E+02
	9	269	0.05	13.45	7.43E-05	5.21E+04	8.33E-09	8.17E-02	2.94E+02	7.06E+03	4.25E+02
	11	258	0.05	12.9	7.75E-05	4.99E+04	7.99E-09	7.84E-02	2.82E+02	6.77E+03	4.43E+02

Radiation hardness

Eloss (MeV/cm-1)			L	Thickness	Width	Volume (cm^3)	Density	Mass (g)			
3.87			5	0.025	0.035	0.004375	2.329	0.0101893 75			3 MRad
	Energy	Rate(kHz/A /W)	Current	Rate kHz	1/Rate (s)	E deposit (MeV)	J	Dose (rad)	Dose per hour (rad)	Dose / day (rad)	N days
MEIC	3	316	3	948000	1.05E-09	3.67E+09	5.87E-04	5.76E+03	2.07E+07	4.98E+08	6.03E-03
	5	298	3	894000	1.12E-09	3.46E+09	5.54E-04	5.43E+03	1.96E+07	4.69E+08	6.39E-03
	6	290	2	580000	1.72E-09	2.24E+09	3.59E-04	3.52E+03	1.27E+07	3.05E+08	9.85E-03
	7	283	1.1	311300	3.21E-09	1.20E+09	1.93E-04	1.89E+03	6.81E+06	1.63E+08	1.84E-02
	9	269	0.4	107600	9.29E-09	4.16E+08	6.66E-05	6.54E+02	2.35E+06	5.65E+07	5.31E-02
	10	258	0.18	46440	2.15E-08	1.80E+08	2.88E-05	2.82E+02	1.02E+06	2.44E+07	1.23E-01
eRHIC	3	316	0.05	15800	6.33E-08	6.11E+07	9.78E-06	9.60E+01	3.46E+05	8.30E+06	3.62E-01
	5	298	0.05	14900	6.71E-08	5.77E+07	9.23E-06	9.05E+01	3.26E+05	7.82E+06	3.83E-01
	6	290	0.05	14500	6.90E-08	5.61E+07	8.98E-06	8.81E+01	3.17E+05	7.61E+06	3.94E-01
	7	283	0.05	14150	7.07E-08	5.48E+07	8.76E-06	8.60E+01	3.10E+05	7.43E+06	4.04E-01
	9	269	0.05	13450	7.43E-08	5.21E+07	8.33E-06	8.17E+01	2.94E+05	7.06E+06	4.25E-01
	11	258	0.05	12900	7.75E-08	4.99E+07	7.99E-06	7.84E+01	2.82E+05	6.77E+06	4.43E-01

Detector technologies

- Radiation hard (3 mA current !)
  - Diamond
  - Silicon (regular/ high radiation / cryo cooled)
- Radiation hard and fast (less 100 ns)
  - Superconducting detector NbN NbTi
  - Quartz detector

- All in vacuum
- Roman pot option

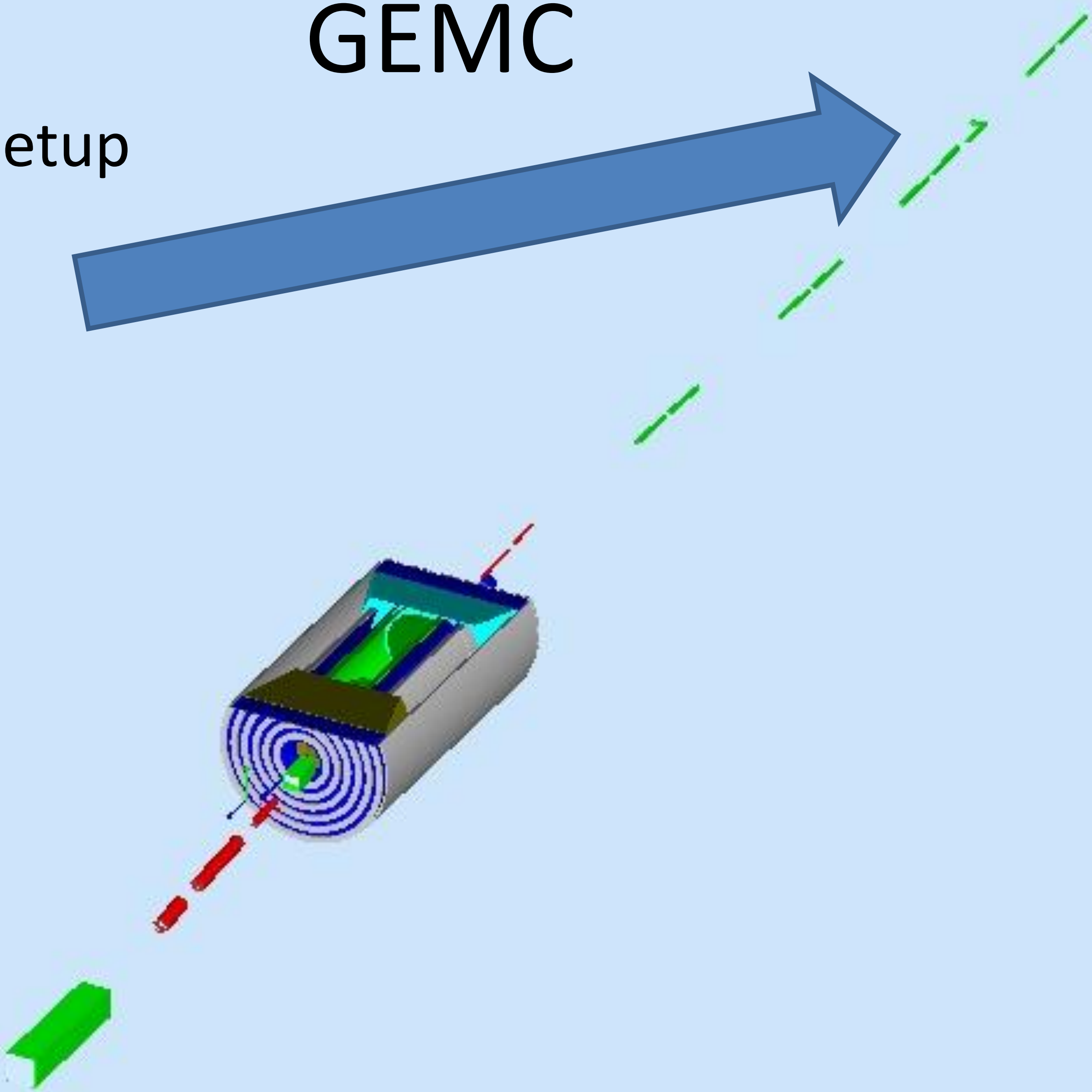
Compton photon vs electron

- Past experience
  - HERA photon only longitudinal and transverse (1.4 %)
  - SLAC : SLD electron detection 50 GeV best Compton measurement ever made 0.5 % (large energy, large dispersion, low rates)

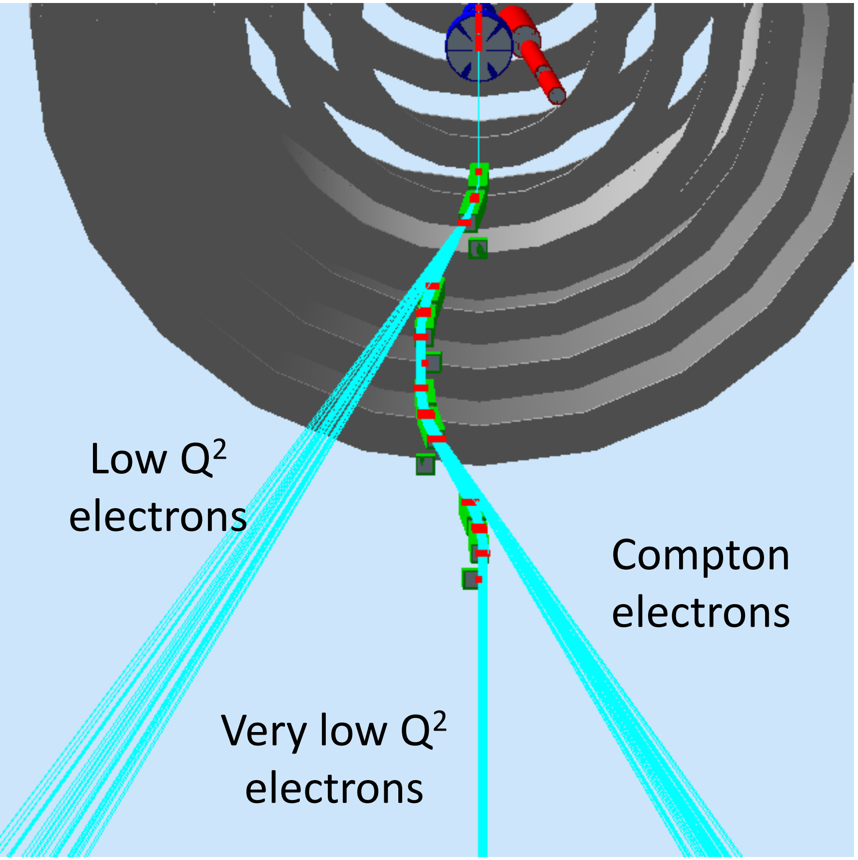
- For Compton electron
  - Larger displacement the better for improved resolution and signal to background ratio
  - Opposite requirement to photon detection where minimum is sought to reduce
- Need to evaluate optimum case : photon only, photon and electron detection, electron detection only
- 2 Ips :
  - one optimized for photon small displacement, longer chicane and magnet to reduce synchrotron radiation
  - one optimized for electron with larger displacement

GEMC

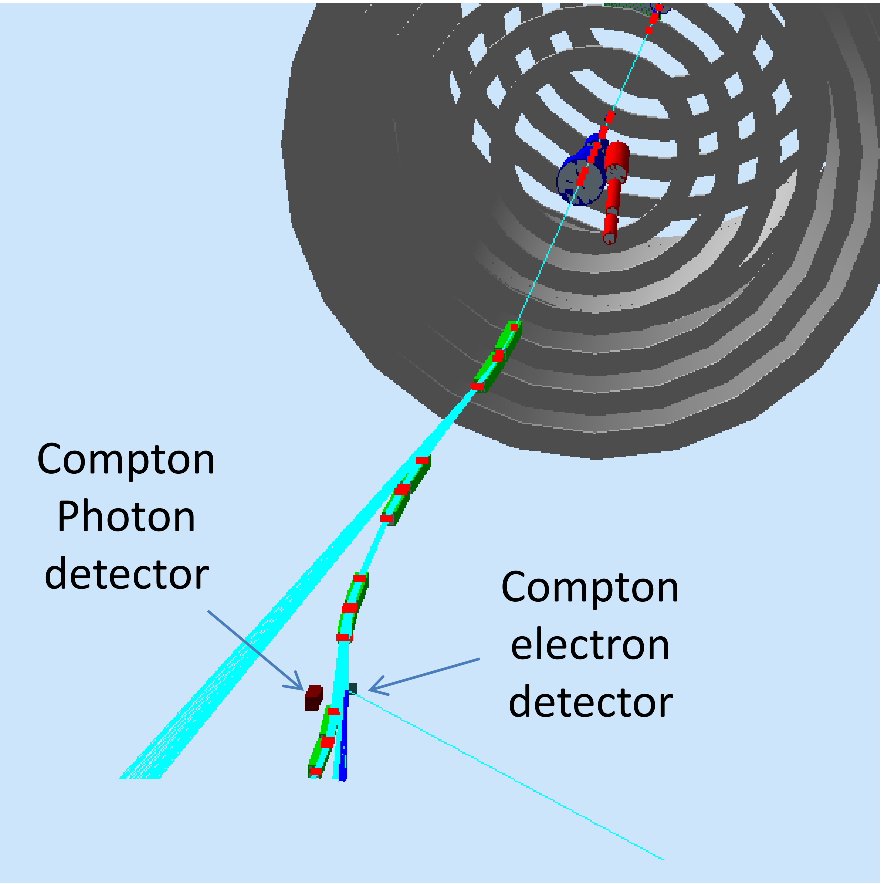
- EIC standard setup
- Easy to add additional detectors
- Need to start looking at background
- Shielding and collimation optimization



Simulation

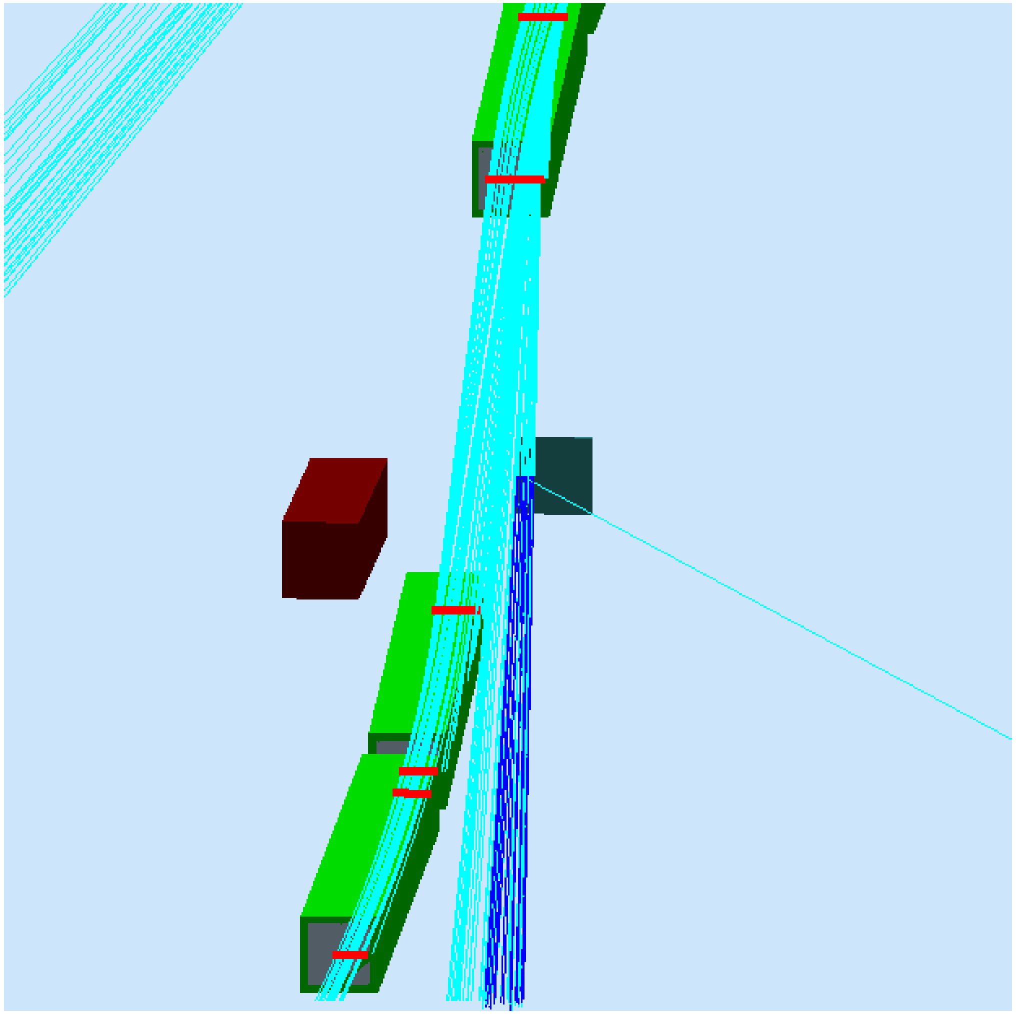


Low Q^2
electrons
Very low Q^2
electrons
Compton
electrons

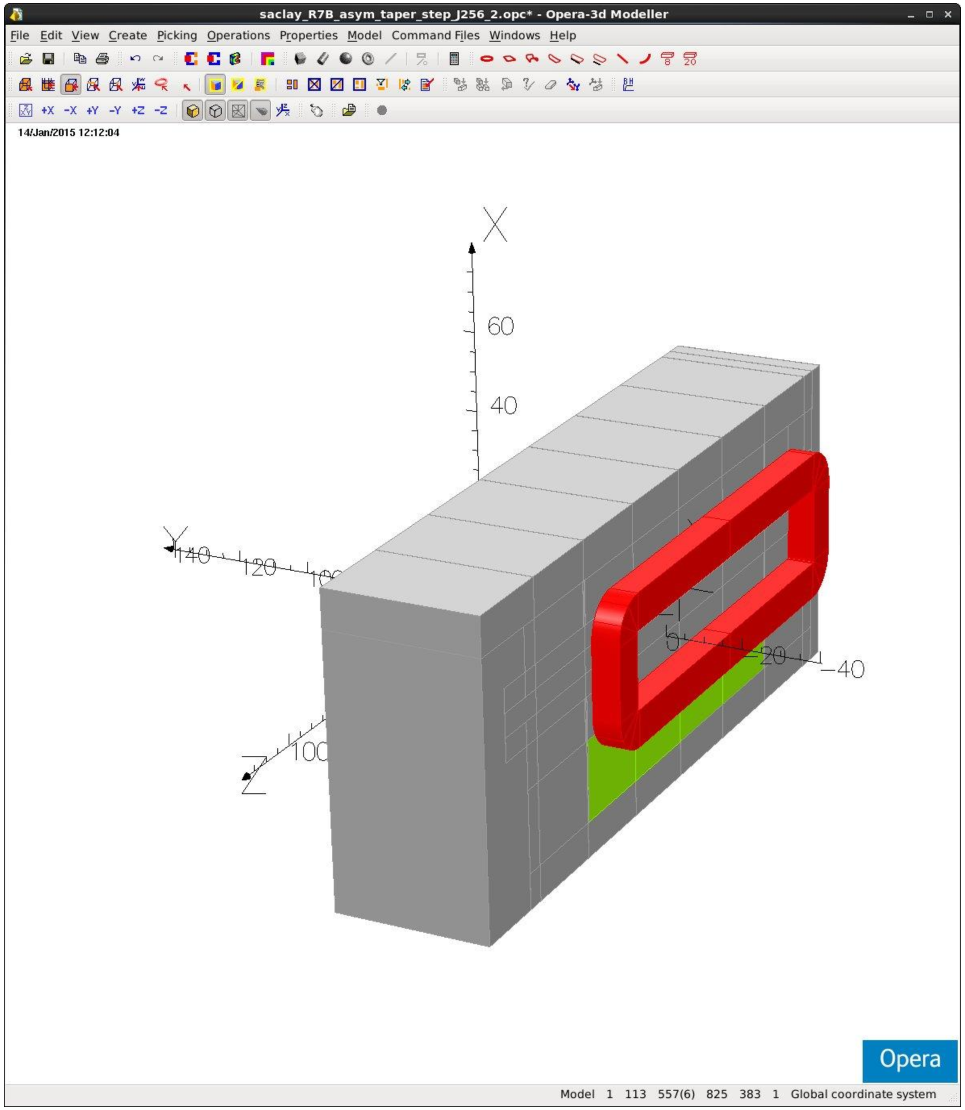


Compton
Photon
detector
Compton
electron
detector

Simulation



Magnet modelling



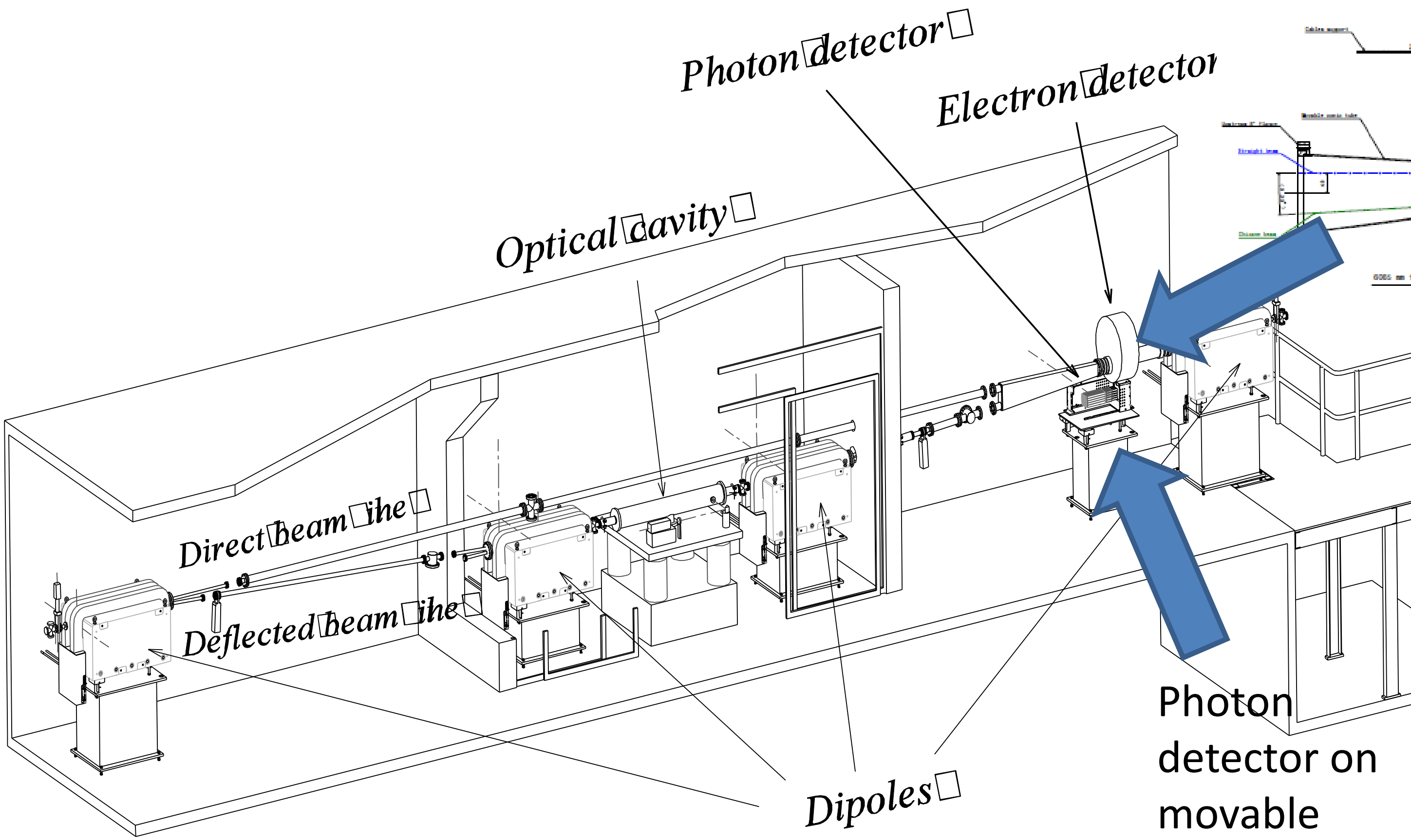
- Opera 3D Tosca
- Use Hall A model as starting point
- Design iron
  - Low Q2 exit
  - Chamber
- Generate accurate fields

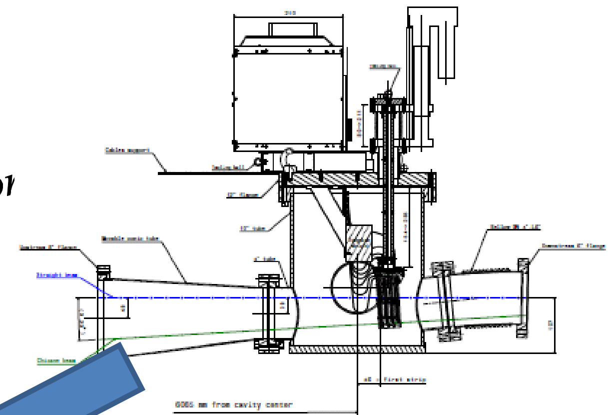
Hall A JLAB 12 GeV status

- First run above 6 GeV : 7.3 GeV
- 2 weeks of physics

- Next run February to May 2015 (5 pass 10 GeV)
  - Tune through Compton chicane
  - Test $PbWO_4$ integrating method
  - Test electron detector

Hall A Compton chicane



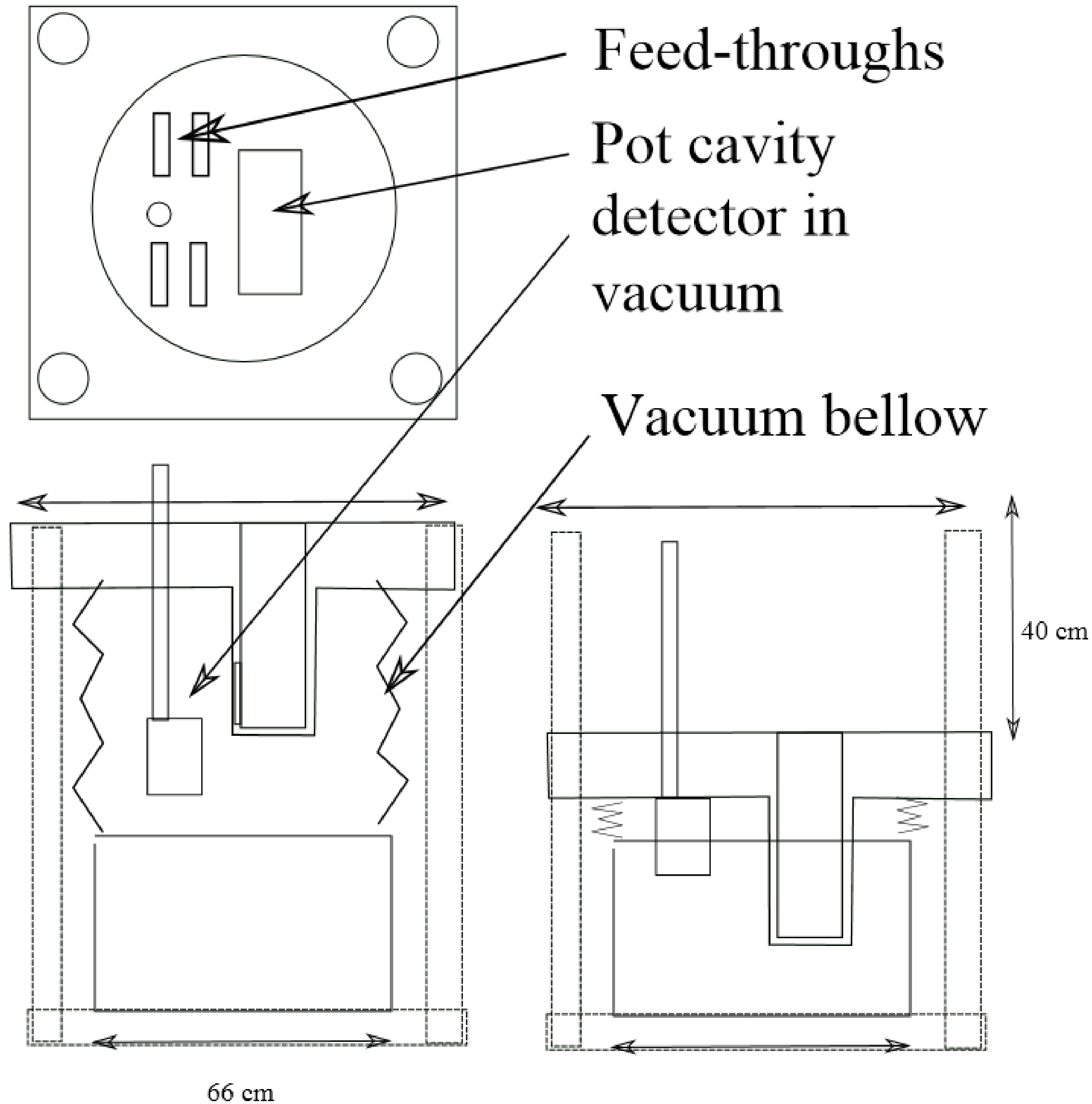


Photon detector on movable table

Vertical motion of electron detector to move detector close to the beam
(up to 5 mm)

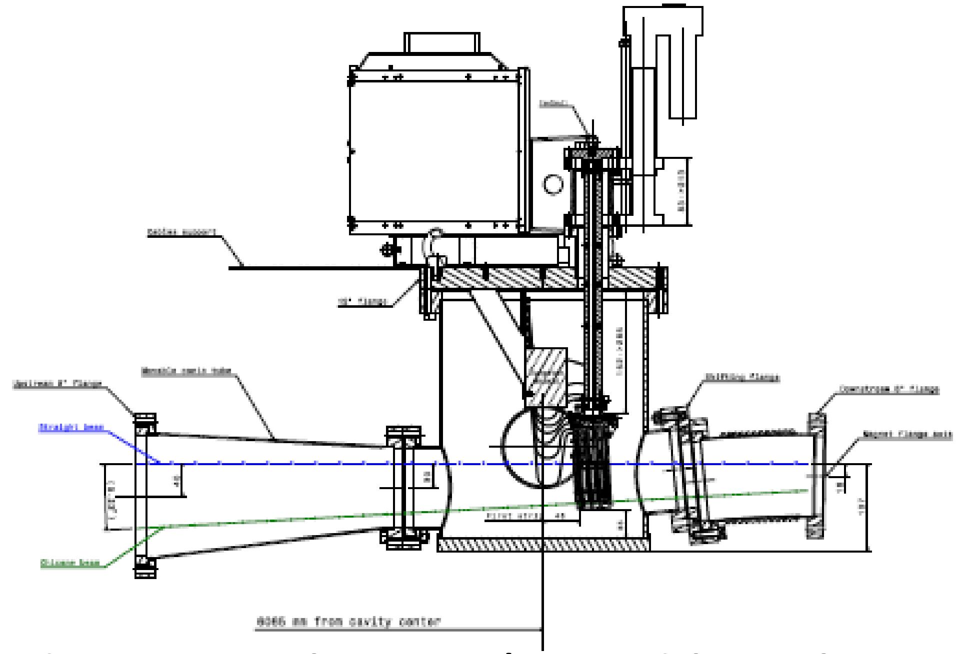
Roman pot technique evaluation in Compton test stand

- Need to evaluation contribution of window
- Evaluate gain in cabling complexity with full vacuum solution



Updated quote

- Bellow expensive
- Simpler design
  - Cheaper
  - More down time
  - Similar design
  - Chamber compatible with silicon, diamond or test detector



  - Top chamber swap for detector change (need break vacuum)

To do list

- Full background simulation
- Evaluation of radiation dose
- Detector cooling
- RF shielding
- Beam pipe, chambers, magnets
- Fast radiation hard photon and electron detectors
  - Design chamber for electron detector
  - Can test photon detector any time
    - Counting vs integrated

Conclusion

- Photon detection need to study effect of shielding
- Electron detection
  - Halo contribution would be useful
  - Simulation in GEMC for background studies
  - Need to handle rate and radiation

Backup

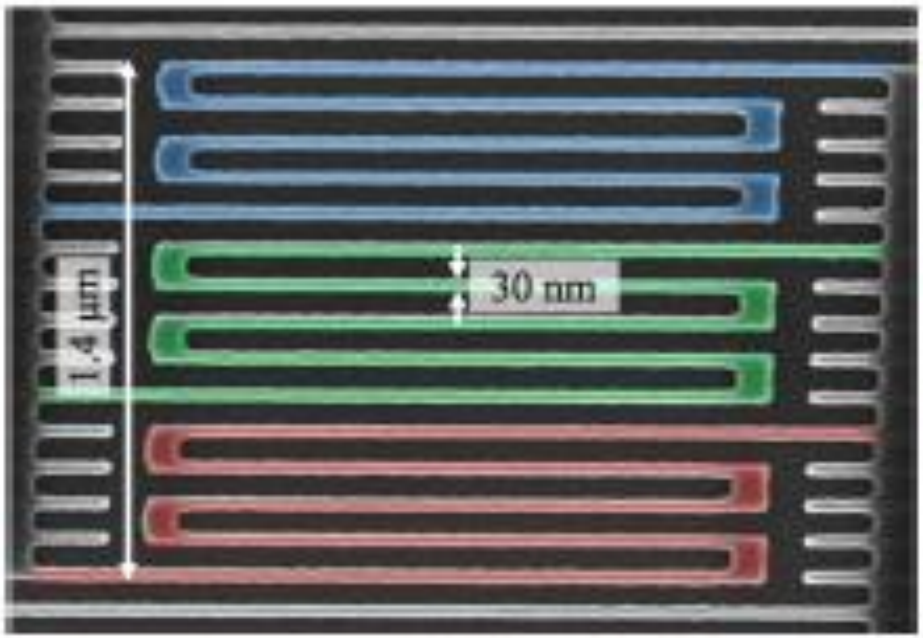
Synchrotron radiation in detector with different shielding 5 GeV

5 GeV beam				
Beam pipe: 10 μm Au, 1 mm Be, 2 mm H_2O and 1 mm Be				
6.61×10^4 γ/bunch 1.10×10^6 keV/bunch	Frac. inc. γs thru	γs thru to det.	Fraction of the inc. energy thru sheet	Energy/bunch on the detector (GeV)
1 mm Cu sheet	3.57×10^{-4}	23.6	9.13×10^{-4}	0.001
500 μm Cu sheet	3.97×10^{-3}	262	9.06×10^{-3}	0.010
200 μm Cu sheet	2.97×10^{-2}	1964	0.0590	0.065
100 μm Cu sheet	8.24×10^{-2}	5445	0.1477	0.162
100 μm Ta sheet	8.32×10^{-3}	550	1.80×10^{-2}	0.0198
50 μm Ta sheet	3.47×10^{-2}	2295	6.74×10^{-2}	0.0741

Synchrotron radiation in detector with different shielding 11 GeV

11 GeV beam (critical energy = 39.4 keV)				
γs and energy that are inc. on detector	Frac. of inc. γs thru sheet	γs thru to the detector/bunch	Fraction of inc. energy thru sheet	Energy/bunch on the detector (GeV)
1.38×10^{9} γ/bunch 4.34×10^{10} keV/bun.	Beam pipe: 10 μm Au, 1 mm Be, 2 mm H_2O and 1 mm Be			
2 mm Cu sheet	0.399	5.50×10^{8}	0.472	2.05×10^{4}
1 mm Cu sheet	0.656	9.06×10^{8}	0.711	3.09×10^{4}
6.42×10^{7} γ/bunch 2.02×10^{9} keV/bun.	Beam pipe: 25 μm Au, 1 mm Be, 2 mm H_2O and 1 mm Be			
2 mm Cu sheet	0.459	2.95×10^{7}	0.531	1.07×10^{3}
1 mm Cu sheet	0.656	4.21×10^{7}	0.711	1.44×10^{3}

Single Superconducting Nanowire Photon Detectors (SNSPD)



•Thin superconducting stripe of 5 to 10 nm thickness

•Meander geometry to maximize surface, typical width of strip 10 nm and length about 100 nm

•Signal speed depends on material, substrate and geometry

•Mostly developed for astrophysics with IR sensitivity : Nasa Jet Propulsion Laboratory, Lincoln Laboratory ….

Comments from report

- The requirements for bunch-to-bunch accuracy of the polarization measurement are essential, but have not been specified. An evaluation of rates and the development of a scheme, which satisfies the requirements for bunch-to-bunch accuracy of the polarization measurement, are essential. A further study of the backgrounds and efforts to find ways how to reduce it, have a high priority.
- The committee considers a high-quality polarization-measurement program essential for EIC and supports the idea of a “Compton polarimeter test bed”. It recommends that the detailed requirements on polarization knowledge be worked out and the resulting detector specifications evaluated, for both EIC machine designs. A close contact between the other groups working on EIC polarization and the machine experts from both EIC machine designs is strongly encouraged.

Comments from report

- In the proposal a clear presentation of the requirements in terms of bunch-to-bunch accuracy, time in which this accuracy has to be achieved, radiation dose in the sensor, and last but not least the rate required to achieve these goals are missing. The committee notes that colliders are repetitive machines and the fate of different bunches is not obviously guaranteed to be the same, due to bunch interactions with the machine structure and dependencies of emittance growth and instabilities on bunch charge. Some study is warranted here, even if the bunch crossing pattern allows all combinations as in MEIC.

Reasons why polarization / Current CAN vary From Bunch to Bunch

Polarization:

Hadrons in a storage ring:

source instabilities

Beam-Beam effects

bunch-to-bunch emittance variation, Characteristic scale can be seen from AGS

RHIC polarization profile variation for different bunches after acceleration

leptons in a storage ring:

Beam-Beam effects

source instabilities

Requirement:

measure polarization with enough statistical precision in sufficiently short time units to monitor polarization as function of time and parameters influencing polarization

→ hadron and lepton polarimetry are critical

❑ ...zation profile for the lepton bunches

...longitudinal direction can be circumvented with 352 MHz RF

Current:

Hadrons & leptons in a storage ring:

Variations in transfer efficiency from pre-accelerator to main ring

→ beam-beam interaction is important, it affects the bunch lifetime during the store

leptons in eRHIC

❑ What fluctuation in bunch current for the electron do we expect

→ limited by Surface Charge, need to see what we obtain from prototype gun

eRHIC lepton polarimeter

- Technology: Compton Back scattering
  - measure photon and lepton → complementary & redundancy
- e-Polarimeter location
  - at IP
    - overlap of Bremstrahlung and Compton photons
    - only possible if we have number of empty p-bunches = # cathodes in gatling gun
      - → luminosity loss
  - before/after IP
  - need to measure at location spin is fully longitudinal or transverse
    - 1/6 turn should rotate spin by integer number of π
    - → segmented Calorimeter
    - → longitudinal polarization → Energy asymmetry
    - → transverse polarization component → position asymmetry
  - After IP:
    - does collision reduce polarization → problem at ILC → for eRHIC very small
    - need to measure at location, where bremsstrahlung contribution is small
  - Before IP:
    - need to find room for photon calorimeter
  - Introduce dog-leg for polarimeter
    - minimizes Bremstrahlung photon impact
    - creates synchroton radiation
- Other considerations:
  - # of cathodes in gatling gun: golden number is 20
    - This guarantees that a hadron bunch collides always with electrons produced from one particular cathode, avoiding/reducing significantly harmful beam-beam effect of electron beam parameter variations on the hadrons